Final Technical Report for

National Aeronautics and Space Administration

NASA Grant NAGW-3492

3/15/93 - 9/15/95

An Investigation of the Induced Magnetosphere of Venus and its Interaction with the Solar Wind

Principal Investigator: C. T. Russell

Institute of Geophysics and Planetary Physics

University of California, Los Angeles

Progress Report

This brief report covers the activities from December 1, 1992 to September 15, 1995 as supported by NAG2-501 (PV project close-out) and NAGW-3492 (VDAP follow-on). We first discuss the data processing accomplishments and then the science results.

Data Processing

All data received from ARC were processed up to the final orbit 5055. This processing included both the experiment data records and the supplemental experiment data records. The processed data that we have been submitting to NSSDC were also submitted up to orbit 5055. This included the 13-sec UADS data for the hour around periapsis and the full resolution data for the one-hour period around periapsis. We also completed copying both the EDR and SEDR data to 6250 bpi tapes for our files and copied these two data sets to 12-inch OPTIMEM optical platters for submittal to NSSDC. We created the first CDROMs of the full processed OMAG data set. Finally we completed microfiching of data plots to orbit 1500 and fulfilled data requests for numerous researchers.

Science Results

Together, these two grants supported (in part) the efforts of 4 graduate students (C. M. Ho, G. K. Crawford, D. Orlowski and G. Lindsay) and a small fraction of researchers C. T. Russell and J. G. Luhmann. C. M. Ho and G. K. Crawford finished their dissertations and assumed postdoctoral fellowships at JPL and in Japan respectively. Below we summarize briefly the achievements of each of these individuals.

a) C. T. Russell completed and published an analysis of distant crossings of the Venus bow shock. This clearly showed that the classic formula of the standoff position of the bow shock (*Spreiter et al.* 1966) was, as Spreiter et al. expected, not appropriate at low Mach numbers. He also analyzed the magnetometer data during the PVO entry phase, finding that the magnetic field strength decreased substantially at low altitude consistent with the earlier finding that any intrinsic planetary magnetic field must be very weak. He also showed that at entry the low altitude ionosphere was strongly magnetized with comparable magnetic and thermal plasma pressures.

b) J. G. Luhmann completed and published a survey of the properties of the interplanetary magnetic field and the solar wind at 0.7 AU. She also conducted a search for reconnection in the Venus magnetotail with negative results. She examined the solar wind compressibility of the Venus tail with K. Gringanz and showed its behavior was consistent with that of Mars for similar solar wind dynamic pressures. She also assisted A. Nagy in a study of the magnetic field effects on the Venus ionosphere electron temperature.

c) G. K. Crawford, graduate student, completed his dissertation entitled, "A Study of Plasma Waves Arising from the Solar Wind Interaction with Venus." In the dissertation he examines the geometry of the VLF and ULF foreshocks which depend intimately on

the orientation of the interplanetary magnetic field and the relationship of the observed VLF emissions to current sheets, such as the ionopause.

d) C. M. Ho, graduate student, also finished his dissertation last year, entitled "Plasma Waves in the Nightside Ionosphere of Venus." In this dissertation he examines the magnetic structure of the nightside wake of Venus and the control of VLF emissions by the magnetic geometry and IMF orientation. He also studied the relationships of VLF waves to magnetic field and plasma gradients in the nightside wake region.

e) T. L. Zhang, who graduated previously under project support, published more of the work performed as a part of his dissertation, comparing the structure of the inner Venus magnetosheath with that predicted from gas dynamic theory.

f) D. Orlowski, graduate student, continued his dissertation research into the behavior of ULF waves in the Venus foreshock. In particular he showed that 1 Hz whistler mode waves damped as expected with distance from the shock. He also showed that the properties of ULF waves were better explained by kinetic theory than by two fluid MHD theory.

g) G. Lindsay, graduate student, also continued her dissertation research into the properties of solar wind disturbances at 0.7AU. She showed that the main causes of interplanetary shocks at 0.7AU were coronal mass ejections, CMEs, and that the number of interplanetary shocks varied strongly over the solar cycle. She next compared the sizes of the disturbances caused in the solar wind by both CMEs and solar wind stream interactions. The largest disturbances were found to be associated with CMEs. Finally, with V. Pizzo of NCAR she began a study comparing the observed properties of stream interactions at both 0.7AU and other heliocentric distances with theory.

In total over the reporting period we published 35 papers in books and journals and made 10 presentations at scientific meetings.

Bibliography NAGW - 3492
(3/15/93 - 9/15/95)

Publications in Journals and Books

1. J. G. Luhmann, T. L. Zhang, S. M. Petrinec, C. T. Russell, P. Gazis and A. Barnes, Solar cycle 21 effects on the interplanetary magnetic field and related parameters at 0.7 and 1.0 AU, J. Geophys. Res., 98, 5559-5572, 1993.

2. T. L. Zhang, C. T. Russell, J. G. Luhmann, J. R. Spreiter and S. S. Stahara, On the spatial range of validity of the gas dynamic model in the magnetosheath of Venus, Geophys. Res. Lett., 20, 751-754, 1993.

3. C. T. Russell, Planetary magnetospheres, Rep. Prog. Phys., 56, 687-732, 1993.

4. C. T. Russell, Planetary lightning, Annu. Rev. Earth Planet. Sci., 21, 43-87, 1993.

5. G. K. Crawford, R. J. Strangeway and C. T. Russell, VLF emissions in the Venus foreshock: Comparison with terrestrial observations, J. Geophys. Res., 98, 15,305-15,317, 1993.

6. C. T. Russell, Comment on "Missing pressure in the dayside ionosphere of Venus" by P A. Cloutier, B. K. Stewart, and H. A. Taylor, Geophys. Res. Lett., 20, 2151-2152, 1993.

7. C. T. Russell, Magnetic fields of the terrestrial planets, J. Geophys. Res., 98, 18,681-18,695, 1993.

8. J. G. Luhmann, S. M. Petrinec and C. T. Russell, Statistical behavior of the IMF during the last solar cycle and its implication for geomagnetic activity studies, in Solar Terrestrial Predictions IV, Vol. 2, edited by J. Hruska, M. A. Shea, D. F. Smart and G. Heckman, 599-606, NOAA, ERL, Boulder, Colorado, 1993.

9. D. S. Orlowski, C. T. Russell, D. Krauss-Varban and N. Omidi, On the source of upstream whistlers in the Venus foreshock, in Plasma Environments of Non-Magnetic Planets, edited by T. I. Gombosi, 217-227, Pergamon Press, Oxford, 1993.

10. D. S. Orlowski, C. T. Russell, D. Krauss-Varban and N. Omidi, ULF waves in Venus upstream region: Critical test for two fluid model, in Plasma Environments of Non-Magnetic Planets, edited by T. I. Gombosi, 229-239, Pergamon Press, Oxford, 1993.

11. C. T. Russell, T. L. Zhang and J. G. Luhmann, On the cause of distant bow shock encounters, in Plasma Environments of Non-Magnetic Planets, edited by T. I. Gombosi, 241-246, Pergamon Press, Oxford, 1993.

12. G. K. Crawford, R. J. Strangeway and C. T. Russell, VLF emissions at the Venus dayside ionopause, in Plasma Environments of Non-Magnetic Planets, edited by T. I.

Gombosi, 253-258, Pergamon Press, Oxford, 1993.

13. M. Verigin, J. G. Luhmann and C. T. Russell, On the Venus ion magnetotail structure, in Plasma Environments of Non-Magnetic Planets, edited by T. I. Gombosi, 259-263, Pergamon Press, Oxford, 1993.

14. K. I. Gringauz, M. Verigin, J. G. Luhmann, C. T. Russell and J. Mihalov, On the compressibility of the magnetic tails of Mars and Venus, in Plasma Environments of Non-Magnetic Planets, edited by T. I. Gombosi, 265-270, Pergamon Press, Oxford, 1993.

15. C. T. Russell, R. J. Strangeway, J. G. Luhmann and L. H. Brace, The magnetic state of the lower ionosphere during Pioneer Venus entry phase, Geophys. Res. Lett., 20, 2723-2726, 1993.

16. C. M. Ho, R. J. Strangeway, C. T. Russell, J. G. Luhmann and L. H. Brace, The nightside ionosphere of Venus under varying levels of solar EUV flux, Geophys. Res. Lett., 20, 2727-2730, 1993.

17. R. J. Strangeway, C. T. Russell, C. M. Ho and L. H. Brace, Plasma waves observed at low altitudes in the tenuous Venus nightside ionosphere, Geophys. Res. Lett., 20, 2767-2770, 1993.

18. R. J. Strangeway, C. T. Russell and C. M. Ho, Observation of intense wave bursts at very low altitudes within the Venus nightside ionosphere, Geophys. Res. Lett., 20, 2771-2774, 1993.

19. C. M. Ho, R. J. Strangeway and C. T. Russell, Evidence for Langmuir oscillations and a low density cavity in the Venus magnetotail, Geophys. Res. Lett., 20, 2775-2778, 1993.

20. G. K. Crawford, R. J. Strangeway and C. T. Russell, VLF imaging of the Venus foreshock, Geophys. Res. Lett., 20, 2801-2804, 1993.

21. G. M. Lindsay, C. T. Russell, J. G. Luhmann and P. Gazis, On the sources of interplanetary shocks at 0.72 AU, J. Geophys. Res., 99, 11-17, 1994.

22. D. S. Orlowski, C. T. Russell, D. Krauss-Varban and N. Omidi, A test of the Hall-MHD model: Application to low-frequency upstream waves at Venus, J. Geophys. Res., 99, 169-178, 1994.

23. C. T. Russell, Planetary upstream waves, in Solar Wind Sources of Magnetospheric Ultra-Low-Frequency Waves, 75-86, American Geophysical Union, 1994.

24. R. N. Singh and C. T. Russell, Lightning on Venus confirmed, in Current Science, 66, Nos. 7 & 8, 550-561, 1994.

25. O. Vaisberg, V. Smirnov, A. O. Fedorov, L. Avanov, F. Dunjushkin, J. G. Luhmann and C. T. Russell, Structure of the Venus Tail, in Solar System Plasmas in Space and Time (edited by J. L. Burch and J. H. Waite Jr.), 207-220, American Geophysical Union, Washington, D.C. 1994.

26. T. Higuchi, G. K. Crawford, R. J. Strangeway and C. T. Russell, Separation of spin synchronized signals, Ann. Inst. Statist. Math., Vol. 46, No. 3, 405-428, 1994.

27. C.-M. Ho, R. J. Strangeway and C. T. Russell, Spatial distribution of plasma wave activity in the nightside ionosphere of Venus, Planet Space Sci., 42, 813-823, 1994.

28. K. H. Baines, R. W. Carlson, D. Crisp, J. T. Schofield, B. Bézard, C. de Bergh, P. Drossart, W. A. Delamere, B. Fegley, W. H. Smith, S. J. Limaye, C. T. Russell, G. Schubert, S. Calcutt and F. W. Taylor, Vesat: The Venus environmental satellite discovery mission, Acta Astronautica, 35, Suppl., pp.417-425, 1995.

29. C. T. Russell, The solar wind interaction with Venus: A comparison of Galileo and Pioneer Venus observations, Adv. Space Res., 15, (4)5 - (4)16, 1995.

30. C.-M. Ho, R. J. Strangeway and C. T. Russell, Venus planetary lightning rate as deduced from VLF bursts, Adv. Space Res., 15, (4)93 - (4)98, 1995.

31. T.-L. Zhang, K. Schwingenschuh and C. T. Russell, A study of the solar wind deceleration in the earth's foreshock region, in Adv. Space Res., 15, (8/9)137 - (8/9)140, 1995.

32. D. S. Orlowski and C. T. Russell, Comparison of properties of upstream whistlers at different planets, in Adv. Space Res., 16, (4)137-(4)141, 1995.

33. D. S. Orlowski, C. T. Russell, D. Krauss-Varban and N. Omidi, Properties of ultra low frequency upstream waves at Venus and Saturn: A comparison, in Adv. Space Res., 16, (4)143-(4)148, 1995.

34. C. M. Ho, R. J. Strangeway and C. T. Russell, Venus nightside ionospheric irregularities and their relationship to VLF bursts, J. Geophys. Res., 100, 9697-9705, 1995.

35. O. Vaisberg, A. Federov, F. Dunjushkin, A. Kozhukovsky, L. Avanov, C. T. Russell and J. G. Luhmann, Ion populations in the tail of Venus, Adv. Space Res., 16, (4)105-(4)118, 1995.

B. Invited Papers

C. T. Russell and R. J. Strangeway, Low altitude magnetic fields and plasma waves, presented at Spring National AGU Meeting, (abstract) EOS 74(16), Spring Meeting Suppl., 186, 1993.

C. Presentations at Meetings

1. R. J. Strangeway, C. M. Ho and C. T. Russell, Plasma wave bursts in the low altitude Venus nightside ionosphere, presented at Spring National AGU Meeting, (abstract) EOS 74(16), Spring Meeting Suppl., 186, 1993.

2. C. M. Ho, R. J. Strangeway, C. T. Russell, J. G. Luhmann and L. H. Brace, IMF control of the nightside ionosphere of Venus, presented at Spring National AGU Meeting, (abstract) EOS 74(16), Spring Meeting Suppl., 186, 1993.

3. G. K. Crawford, R. J. Strangeway and C. T. Russell, VLF imaging of the Venus electron and ion foreshocks, presented at Spring National AGU Meeting, (abstract) EOS 74(16), Spring Meeting Suppl., 248, 1993.

4. G. K. Crawford, R. J. Strangeway and C. T. Russell, Plasma waves observed above the dayside Ionopause of Venus: Evidence for an additional transition layer, presented at Fall National AGU Meeting (abstract) EOS 74(43) Supplement, p.375, 1993.

5. J. D. Mihalov, A. Barnes and C. T. Russell, Correlations of nightside ion flows with magnetic field directions at Venus, presented at Fall National AGU Meeting (abstract) EOS 74(43) Supplement, p.376, 1993.

6. T-L Zhang, K. Schwingenschuh, E. M. Dubinin, C. T. Russell and J. G. Luhmann, The magnetic barrier at Venus and Mars, presented at the Annual EGS meeting, April, 1994.

7. O. Vaisberg, A. Fedorov, F. Dunjushkin, V. Smirnov, L. Avanov, C. T. Russell and J Luhmann, Ion populations in the tails of Venus and Mars, presented at the 30th COSPAR Scientific Assembly, Hamburg, July 1994.

8. T. Mulligan and C. T. Russell, Solar wind and IMF at Venus during Halley's inferior conjunction, presented at the Fall Annual AGU meeting (abstract) EOS, 75(44) Supplement, 411, 1994.

9. R. J. Strangeway and C. T. Russell, Plasma waves are not a heat source for the dayside Venus ionosphere, presented at the Fall AGU Meeting (abstract), EOS, 76(46), Supplement, 339, 1995.